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ANALYSIS OF DISPERSED SURFACE WAVES FROM NORSAR LONG PERIOD SITES

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The bandwidth available for study of NORSAR long period data has been significantly extended, to periods well beyond 200 seconds, even though the recording system is sharply peaked near 20 seconds, through the use of frequency domain compensation for instrumental magnification and phase shift.

Inhomogeneities in the lithosphere, especially those in portions of the Oslo Graben near the NORSAR site, affect the propagation of surface waves in

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this region at least as much as they disturb the progressive wave fields of compressional arrivals. Scale sizes of these lithospheric inclusions ranging to over one hundred kilometers, according to body wave estimates, are thus sufficient to account for lateral refraction and reflection, scattering, non-least-time, and off-great-circle arrivals at remarkably long periods. Two dimensional frequency wave number (f-k) analysis of raw dispersion data reveal azimuthal perturbations of more than twenty degrees, even at periods greater than one hundred seconds. Such f-k analyses of raw dispersion data yield all but useless phase velocities for the array site. Frequency-time analysis, time variable filtering, longitudinal-vertical coherency and ellipticity filtering provide relatively rapid and inexpensive sample trace processing schemes which can efficiently improve frequency-wavenumber iteration of useful phase velocity estimates.

FOREWORD

This final report for AFCRL contract F19628-73-C-0285 constitutes a small increment in a continuing series of surface wave studies of the Earth's crust and upper mantle at the University of Texas at Dallas. These studies have been based upon the use of modern methods for the analysis of dispersed elastic waves; a significant proportion of these developments have originated within our research group. The present report deals primarily with surface wave studies at NORSAR, which were performed under the auspices of the Air Force Cambridge Research Laboratories. Various portions of this material were reported during and as part of an invited lecture "Analysis of Oscillations" (Landisman 1975), to the XVI General Assembly of the International Union of Geodesy and Geophysics, which was convened in Grenoble, France, during August-September, 1975. Additional material in this report, and other related topics will appear in other studies, such as that by Nyman and Landisman (1976).

This research project is sponsored and supported by the Advanced Research Projects Agency of the Department of Defense. The task of technical supervision has been carried out by the Air Force Cambridge Research Laboratories, Stanley M. Needleman, Project Scientist.

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This report has been reviewed and is approved.

Mark Landisman, Professor
Principal Investigator
The University of Texas at Dallas

Final Technical Report

I. Introduction

Recent research, including seismological and gravity studies of the Oslo Graben (Ramberg and Smithson, 1975) and, more particularly of the NORSAR site (Berteussen, 1975) have tended to emphasize the geologic and tectonic complexity of the region near this array site. Aki, et al (1975), for example, have presented evidence for pipe-like geological structures under NORSAR, which were interpreted to be the result of plastic deformation of the local lithosphere. The discussion of these anomalies included consideration of possible consequences of the ascent of magma associated with Permian volcanism in this portion of the Oslo Graben. The widely observed inhomogeneities in wave propagation for the compressional waves recorded at NORSAR are related to inhomogeneities concentrated in the lithosphere beneath the array (Berteussen, 1975). The scale sizes for the inferred lithospheric inclusions, as judged from spectral analyses of these perturbations of the compressional wave field, range from several tens to over a hundred kilometers (ibid).

The propagation of long period, teleseismic Rayleigh and Love waves tends to be relatively undisturbed by lithospheric variations near the smaller end of this size distribution, since the smallest lengths of these surface waves certainly exceed some several tens of kilometers. The larger elements of this distribution of inhomogeneities, however, appear to represent an extremely serious problem for propagating elastic surface waves. As a result, lateral refraction and reflection, scattering, off-great-circle and non-least-time arrivals seem to be at least as common for teleseismic surface wave arrivals at NORSAR as they are for teleseismic body wave arrivals.

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2. Review

Our NORSAR surface wave studies have centered on several main types of problems. First, we concentrated on the determination of and compensation for long period instrumental effects. These efforts received direct assistance from laboratory determinations of the magnification curve (Gudzin, 1968) and synoptic measurements of the appropriate instrumental constants at the NORSAR long period site, kindly supplied by J. Woolson of the Teledyne-Geotech Seismic Data Laboratories in Alexandria. Compensation for the magnification and phase shift according to the frequency domain equalization techniques proposed by Deregewski (1971), was greatly favored by the fact that the data were originally recorded as digital time series. They therefor possess a far greater dynamic range than is ordinarily available for older, visible recordings.

Frequency domain compensation for the recording system response (ibid) broadens the usable bandwidth of recorded signals to a remarkable degree. It also distinctly extends the range of applicability of these surface wave studies. For example, whereas the original recordings appear to consist almost entirely of signals having periods of from twenty to thirty seconds because the system magnification is sharply peaked near periods of twenty five seconds, the compensated recordings have permitted the study of dispersion data from periods ranging from less than fifteen seconds to more than two hundred seconds.

Further efforts were concerned with determination of the dispersion of Rayleigh waves for the Eurasian landmass for paths close to potential test sites. One of the most successful ways to accomplish this task involves the use of frequency-time analysis (FTAN) of the time series (Landisman, et al., 1969) recorded at the various NORSAR long period sites, after instrumental compensation, as discussed above. FTAN processing permits determination of the observed average group velocity for the path between the source and the array site.

A series of publications has described the multiple filter process, which often has been used for frequency-time analysis (Dziewonski, Bloch, and Landisman, 1969; Landisman, et al., 1969; Dziewonski, Landisman, et al., 1968). This process yields displays of "instantaneous" spectral amplitude and phase as functions of log period and linear group velocity. During this phase of our research, Dr. Douglas C. Nyman became impressed with the fact that equalization of the velocity and period resolution of such displays would be a distinct improvement over previous analyses based upon a constant relative band width, α, (Dziewonski, Bloch, and Landisman, 1969). The display equalized multiple filter process (Nyman and Landisman, 1976) employs a locally variable bandwidth

$$\alpha(T_j, v_k) = \Delta\ \delta v\ T_j / (4\pi\epsilon\ v_k^2),$$

where Δ = epicentral distance,

δv = linear step in analysed group velocity between adjacent rows of display,

T_j = period being analysed,

ϵ = fractional change in period between adjacent columns of display,

and v_k = group velocity being analysed.

The display equalized filter thus defined is a function of the particular period or velocity of interest in contrast to the previously used constant relative bandwidth filter function, α, which tended to have excessively great velocity resolution at short periods and low group velocities, and excessive frequency resolution at long periods and high group velocity values. Compare Figures 1a and 1b. The resolution is also independent of the shape of the dispersion curve and of the spectral excitation (Nyman and Landisman, 1976). The use of this form of frequency-time-analysis has enabled us to make accurate estimates of the observed Rayleigh wave disperison at each long period site, and has permitted the construction of time variable filters (Landisman, et al., 1969; Dziewonski, Landisman, et al., 1968) for isolation of the fundamental Rayleigh

mode signal on the vertical and longitudinal components at each NORSAR long period site (Figure 1c). Further purification of these signals was derived from the methods based upon the use of three component recordings to emphasize those signals arriving from the proper azimuth, with the expected retrograde elliptical motion, and with expected amplitude ratios between the longitudinal and vertical components.

All of these criteria plus the coherency of the longitudinal and vertical arrivals were used to improve the purity of the dispersed Rayleigh mode arrivals, especially the purity of their phase functions. We previously had attempted to determine the phase velocity dispersion curve in the vicinity of the NORSAR array site, through the analysis of "raw" observations of the dispersed wavetrains. The results for both ordinary and high-resolution frequency wavenumber processing (McCowan and Lintz, 1968) of such data were all but meaningless. Careful study of the long period horizontal recordings showed that pseudo-random lateral refractions are an important component of the problem: two dimensional frequency wavenumber analyses showed that azimuthal errors of the order of twenty degrees can be observed, even for time variable filtered data, and for periods that exceed 100 seconds. This is surely a strong confirmation of body wave studies (Aki, et al., 1975) as well as of regional geological and geophysical investigations (Ramberg and Smithson, 1975), that lateral inhomogeneities having scale sizes in excess of one hundred kilometers can significantly influence wave propagation in the vicinity of the NORSAR array.

These and similar effects naturally become still more important at shorter periods and shorter wavelengths. Monitoring of the longitudinal-vertical coherency and of the azimuthal deviations of the dispersed arrivals appears to provide a reasonable means of predicting those portions of the spectrum that correspond primarily to the great-circle-azimuth, least-time dispersed arrivals. These predictions tend to be confirmed in most cases by the two dimensional frequency wave number analyses of the horizontal recordings. Viz: those portions of a dispersed wavetrain that arrive from azimuths close to the great circle direction of

approach also exhibit good longitudinal-vertical coherency and expected values of ellipticity. The converse statement is usually observed as well. This is of distinct significance, since the relatively rapid analysis of a few sample traces can thus be used with considerable confidence as a guide to the use of slower, more expensive frequency wavenumber analysis of data from the entire array.

The improved, though still fairly rough phase velocities defined by this process should be able to be refined by iterative analyses of a large suite of events arriving at the array site from a wide range of azimuths. This investigation will be continued in future studies, depending in part upon the availability of funds.

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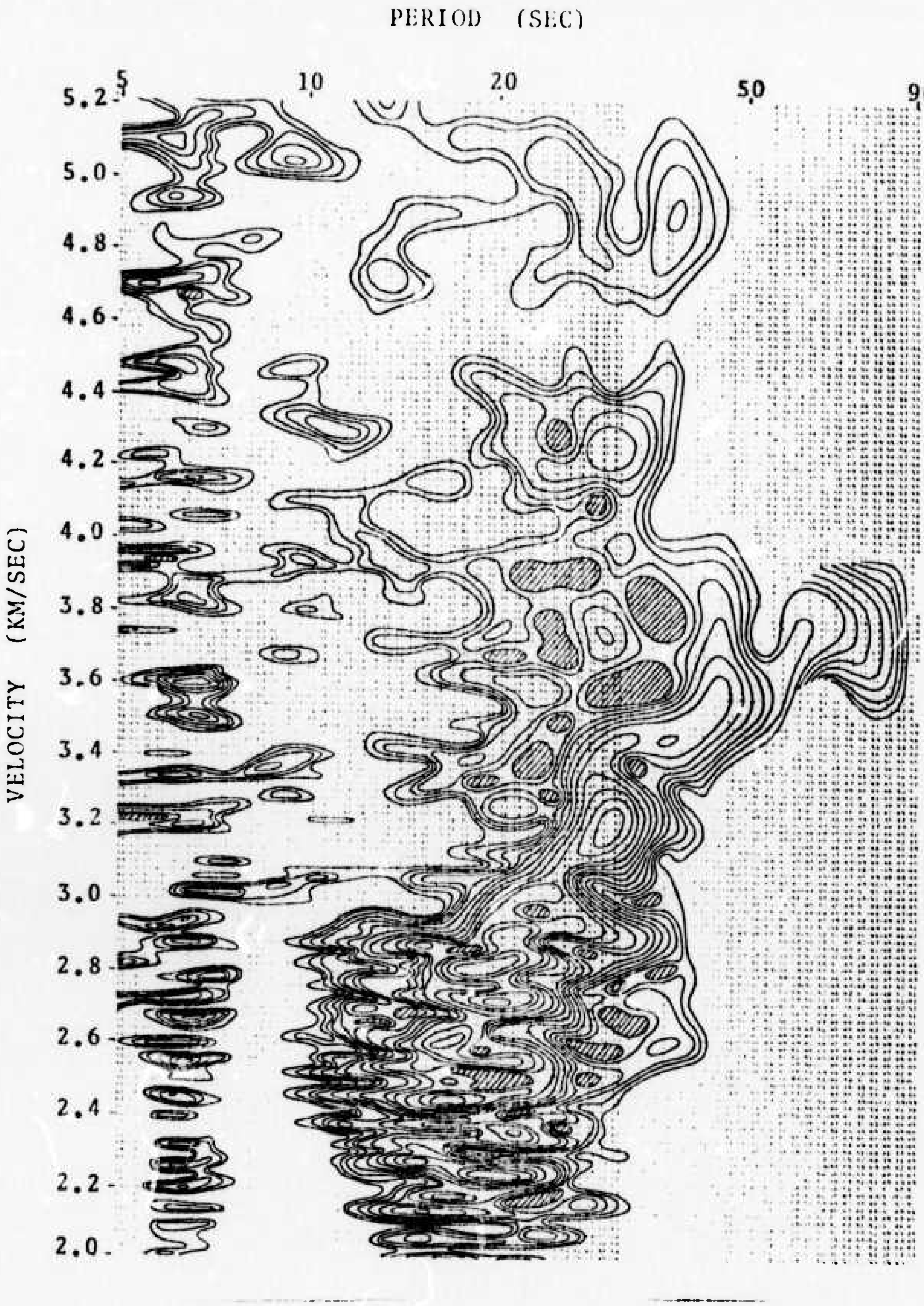

FIGURE 1A
Frequency-time analysis, using constant relative bandwidth, for NORSAR recording of Java event, m_b=6.1, 4 May 1961, Δ=98°.

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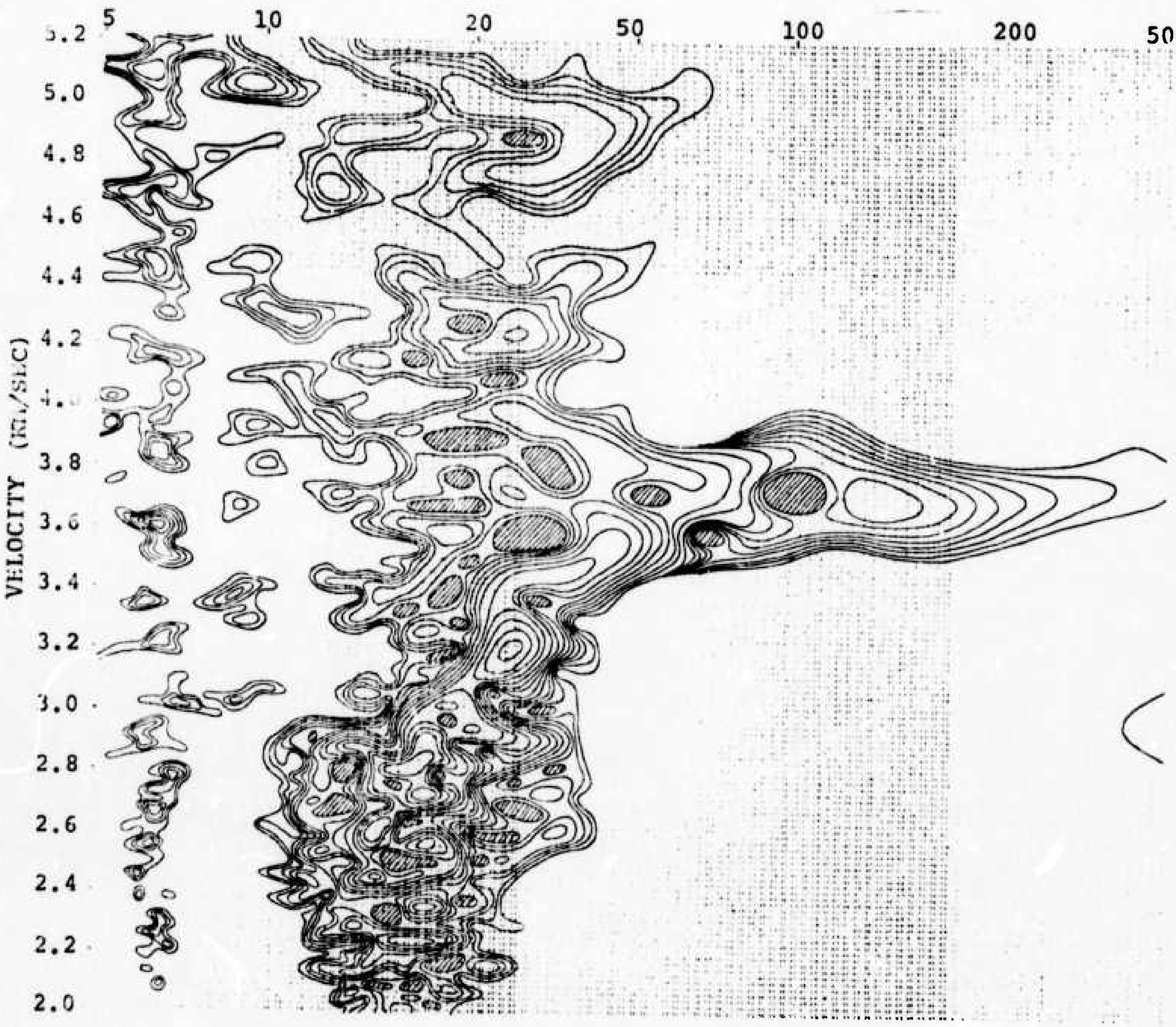

FIGURE 1B

Frequency-time analysis of same data as in Figure 1a, processed by display equalized filter.

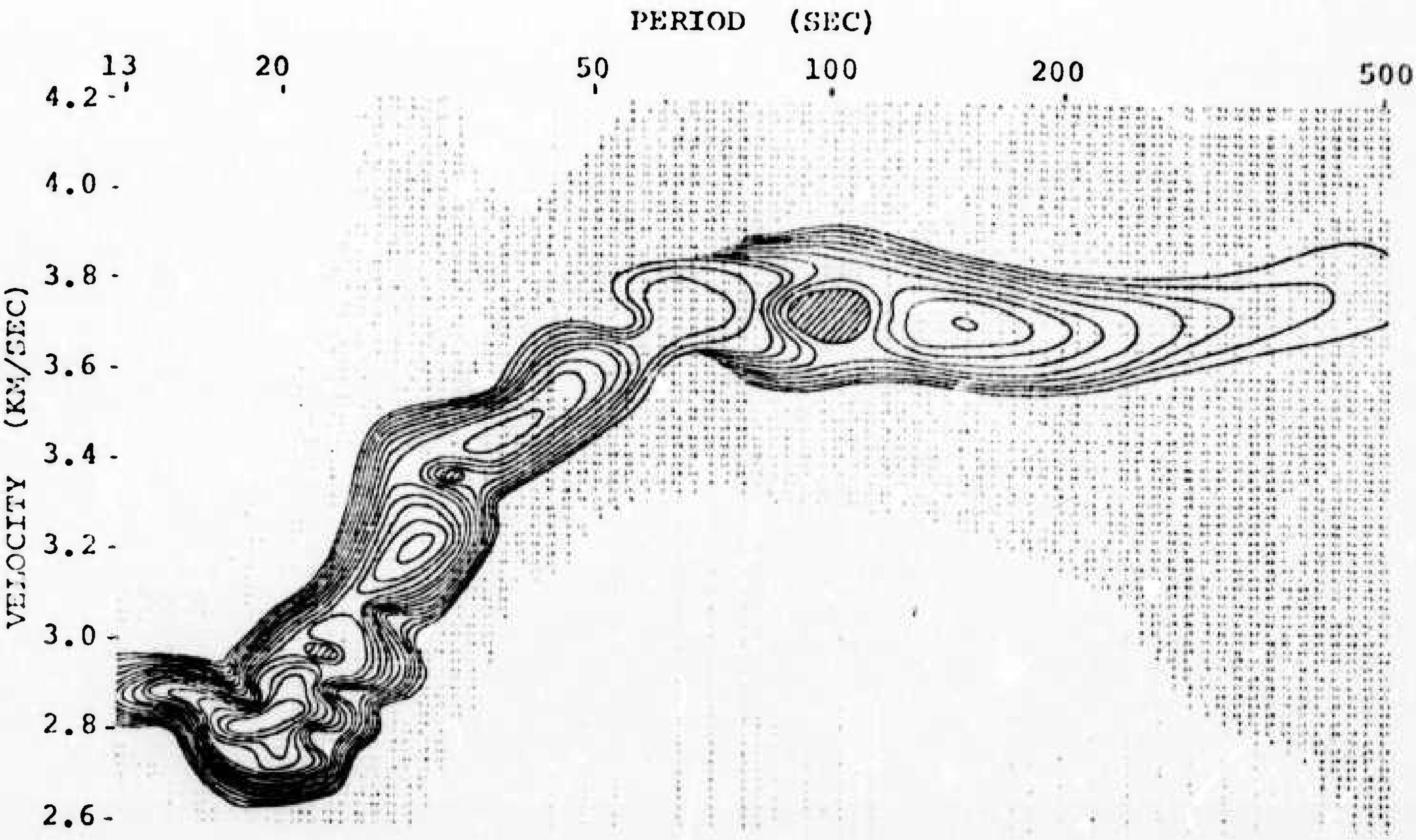

FIGURE 1C
Frequency-time analysis as in Figure 1b, after time variable filtering to extract dispersion for the fundamental Rayleigh mode.